CHARACTISTIGS OF A SPHERICAL GEIGER-MULLER TUBE

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I. INTRODUCTION

In most of the articles and books published on the operating characteristics of Geiger-Müller counters the data are based on some type of cylindrical or plane geometry. However, articles concerning spherical geometry throughout the counter were published in 1942 by Hajewsky (1) and Hajewsky, Dorneich, and Dreblow (2). Other workers, Salvini (3, 4), worked with a spherical cathode and a wire loop anode. Hajewsky (1, 2) did not give the procedure and final results of the operating characteristics of a spherical Geiger-Müller counter. It is of interest to determine the operating characteristics of different counter geometries to make use of the optimum geometry for a particular application.

The object of this investigation is to investigate the directional characteristics of a spherical Geiger-Müller counter and to describe the experimental procedures and techniques involved in the construction and operation of one such counter.

II. GENERAL DISCUSSION

A detailed description of the Geiger-Müller discharge is given in Wilkinson (5). Briefly, however, the mechanism is as follows.

When a gamma ray impinges on the tube walls or traverses the counter gas, ionization within the wall or in the gas may release an electron. When a beta particle strikes the wall of the counter tube it may, with sufficient energy, pass into the sensitive volume of the tube. In either case, an electron enters the counting volume and in its travel through the counter gas causes primary ionization of some of the gas within the counter. The electrons released are accelerated toward the anode and at a point close to the anode produce further ionization. The ionization builds up rapidly in this manner and causes an avalanche of electrons approaching the anode. This is referred to as the Townsend avalanche. The primary avalanche begets secondary avalanches principally from the photo electrons produced in the ionizing event. All of the secondary avalanches are initiated near the wire as shown by Stever (6) in his experiments using small glass beads on the wire.

The ionization takes place very near the anode since the

energy imparted to the avalanche and hence the probability of ionizing further molecules is proportional to the electric field. This can be explained by the following equation for the electric field around a spherical anode inside a spherical cathode:

$$E = \frac{r_a r_c}{(r_c - r_a)} \quad \frac{V}{r^2}$$

where r_a is the radius of the anode, r_c is the radius of the cathode, V the potential difference between the cathode and the anode and r is the point in question. When $r_a << r_c$ the equation reduces to:

$$E = \frac{r_a V}{r^2}$$

Thus the field is not appreciably affected by changes in cathode radius. Also the maximum field is $\frac{V}{r_a}$ whereas for the cylindrical counter the maximum field is $\frac{V}{r_a \ln \frac{r_c}{r_a}}$. Thus it would be expected that a higher voltage would be required for the spherical counter than for the cylindrical counter.

For the initial discharge to originate a second avalanche it is necessary that $N(1)\epsilon > 1$; where ϵ is the probability per ion, of any avalanche, that another avalanche will be generated by a photoelectric process and N(1) is the number of ions produced in the first avalanche. This is a necessary

but not a sufficient condition for a secondary avalanche to be generated since the avalanche is a statistical phenomenon and may be broken off at any point due to statistical fluctuations. When $N(n)\epsilon \leq 1$ the discharge terminates. At this time avalanche production becomes a convergent process because the reduction of the field immediately surrounding the anode is reduced by the positive ion sheath. The entire production of the avalanches takes place in a fraction of a micro-second.

During the production of the avalanches a positive ion sheath is produced around the anode. In the short time of the discharge the positive ion sheath can be considered stationery. The positive ion sheath then moves toward the cathode. In counters containing pure gases, the positive ions will reach the cathode and combine with electrons from the metal of the cathode. There are two possibilities of producing electrons when the positive ions reach the cathode. The first is that the difference between the ionization potential of the ions and the work function of the cathode releases a photon which in turn may release a photo electron, and the second is that the ions may release an electron directly from the cathode. In the above type of counter some type of external quenching circuit is necessary since there is no internal quenching.

In this investigation it was decided to build a

self-quenching counter. In general, a counter may be made self-quenching by adding an impurity to the principal filler gas, such as argon. A polyatomic gas such as ethanol, or other organic vapor, or a halogen is often added as the impurity. Korff and Present (7) explained the quench mechanism as follows. The positive ions, in traveling from the anode to the cathode, collide with the impurity molecules such as ethanol. The ethanol molecules have an ionization potential of 11.3 volts while the argon atoms have an ionization potential of 15.7 volts. Thus the difference in ionization potentials transfer the energy to the ethanol molecules. The ethanol molecules reach the cathode and are neutralized not by photon or electron emission, but by dissociation. Therefore, those tubes having organic vapor as the impurity have a finite life. Tubes filled with a halogen, however, often have a longer life since the atoms recombine to form a halogen molecule.

Other organic quench vapors such as methane may be used. However, methane is far down the dissociation chain of a substance such as ethanol and therefore will have a shorter life than ethanol.

A typical tube filling might be 90 mm. argon and 10 mm. ethanol. According to Spatz (8), the tube filled with this mixture would correspond to a life of about 10^{10} counts with a dissociation of 10^{9} atoms per discharge.

The input to the electronic scaler is $V = \frac{Q}{C}$ where V is voltage input, Q is the charge or the number of ion pairs formed per discharge times the charge e, and C is the capacitance of the counter. Typical values of the pulse height are 0.4-40 volts depending on the particular design of the counter.

It is impossible to predict the exact number of ions released in the avalanches and the number of ions formed in the primary ionizing event because both processes are statistical in nature. Normally however, it is expected that at least one ion will be formed when a beta particle goes into the sensitive volume of the tube. Thus it is expected that the counting of beta particles will be about 98% efficient.

It is desirable in some applications to obtain a tube that is non-directional and a tube that will give point counts.

The normal cylindrical counter and the plane counter are directional to some extent and give line activity and plane activity respectively. The purpose of this investigation is to determine the directional characteristics of a spherical Geiger-Müller tube.

III. REVIEW OF LITERATURE

In 1937 Trost (9) discovered that by the addition of a small amount of vapor of certain organic compounds the discharge of a Geiger-Müller tube was quenched. This discovery led to the elimination of the external electronic quenching circuits and to the development of the self-quenching tubes that are in use today.

Montgomery and Montgomery (10) pointed out the major difference between a self-quenching counter and an externally quenched counter. In an externally quenched counter secondary electrons are formed at the cathode when the positive ion sheath is neutralized at that point, whereas there are no secondary electrons from the self-quenching tube. The secondary electrons result in a second avalanche giving continuous discharge.

Korff and Present (7) explained this phenomenon by use of the predissociation characteristics of a polyatomic molecule. The polyatomic molecule usually predissociates before releasing the excitation energy by radiation whereas the monatomic molecules cannot predissociate and thus re-radiate the excitation energy. The excitation energy of the monotomic molecules is radiated as photons and the photons

are absorbed by the polyatomic molecule.

According to Korff (11), the photons emitted by argon range from 1070Å to 790Å wavelength. Hollefson and Burton (12), found that ethanol has a continuous absorption spectrum below a wavelength of 2000Å. Therefore, all the excited photons will be absorbed by ethanol.

Spatz (8) found evidence of decomposition of alcohol vapor in a fast counter. This can occur both by impact by the monatomic molecules and by photo-dissociation. These dissociated products are present in the counter as free radicals that may or may not recombine with some other radical to form a complex organic material. Some products of dissociation are in turn a quenching agent. This will account for the life of the alcohol vapor being longer than the life of methane as the organic constituent in the counter. However, the longer chain hydrocarbon should not be too complex because of the desired mobility of the molecule and because the longer chain molecule that is formed will deposit on the electrodes.

Spatz (8) found that the flatness of the plateau for the Geiger-Müller tube was dependent on the amount of alcohol vapor present. He found that an alcohol pressure of 5% gave a flat plateau and a 10% alcohol pressure gave a slope of 2.0% per 100 volts. Spatz further found that the counter filled with alcohol vapor had an order of magnitude longer

counting time than counters filled with methane.

Najewsky (1) built a spherical tube in 1942 with basically the same design as the tube in this investigation. However, he used bakelite for the wall material and carbon for the cathode. Najewsky reported good results with this tube but gave no data to support that claim.

IV. EXPERIMENTAL PROCEDURES

A. Construction of Counter

The counter was constructed of standard materials. Figure 1 shows the important constructional details of the second counter tube used.

The first tube tried was one constructed by a previous student with the following basic differences from the tube shown in Figure 1. The 1/16 inch diameter anode wire was extended to the center of the counter with a nickel ball on the end which was obtained by melting a small amount of nickel on the end of the anode. The glass sleeve extended to 1/8 inch from the nickel sphere on the end of the anode. The nickel ball was not smooth and it was impossible to correct the deficiencies and hence another tube was constructed.

The anode of the second counter was constructed in the following manner. A 5-mil tungsten wire was attached to a 1/16 inch diameter tungsten wire. A ball bearing 1/16 inch in diameter was annealed, then drilled with a small hole to the center of the ball bearing. The tungsten wire was then crimped on the end, placed in the hole in the ball bearing and soldered in place in such a manner that the ball was 1/8

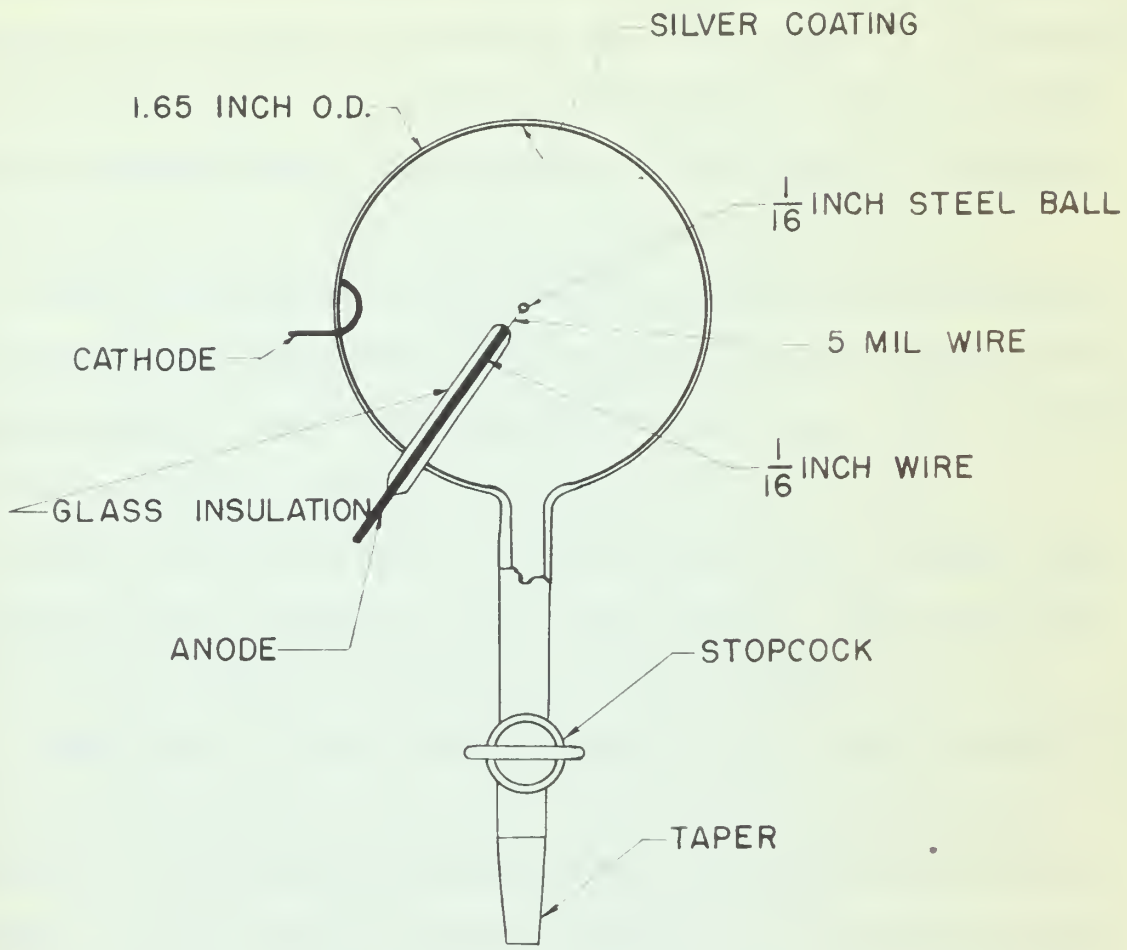


Figure 1. Cross section of spherical Geiger-Müller tube

inch from the end of the heavier wire. A glass sleeve was then placed over the heavier wire to the end of that wire.

A standard 50-ml. spherical flask was used for the shell of the counter. A 50-mil wire passed through the wall of the flask to the inside then through the wall again to the outside of the flask wall. An end was left protruding to act as the cathode connection to the counter. This is shown in Figure 1.

The anode with the metal ball on the end was then introduced into the flask with the metal ball in the center of the inside volume. Both the cathode and anode were then carefully sealed to make a vacuum tight seal.

The neck of the tube was then cut off and a vacuum stopcock and taper attached to the glass sphere. This was done for ease in filling and changing of the filling.

The inside of the counter tube was next silver coated by standard techniques with great care to prevent the silver solution from coming in contact with the anode thereby producing a short circuit with the cathode. The inside of the tube was then carefully dried and washed with acetone before testing the tube. The tube was then checked for short circuits before evacuating and filling.

It was found by measurement that the wall thickness of the tube varied from 320-400 mg/cm^2 with an average thickness of 360 mg/cm^2.

B. The Vacuum System

The vacuum system shown in Figure 2 was used both to prepare the counter mixture and to evacuate and fill the counter tube.

The system was a standard manifold system consisting of a mechanical forepump manufactured by W. M. Welch Manufacturing Company. The diffusion pump was manufactured by Distillation Products, Inc. Figure 2 shows the diffusion pump could be connected and disconnected at will from the main vacuum system.

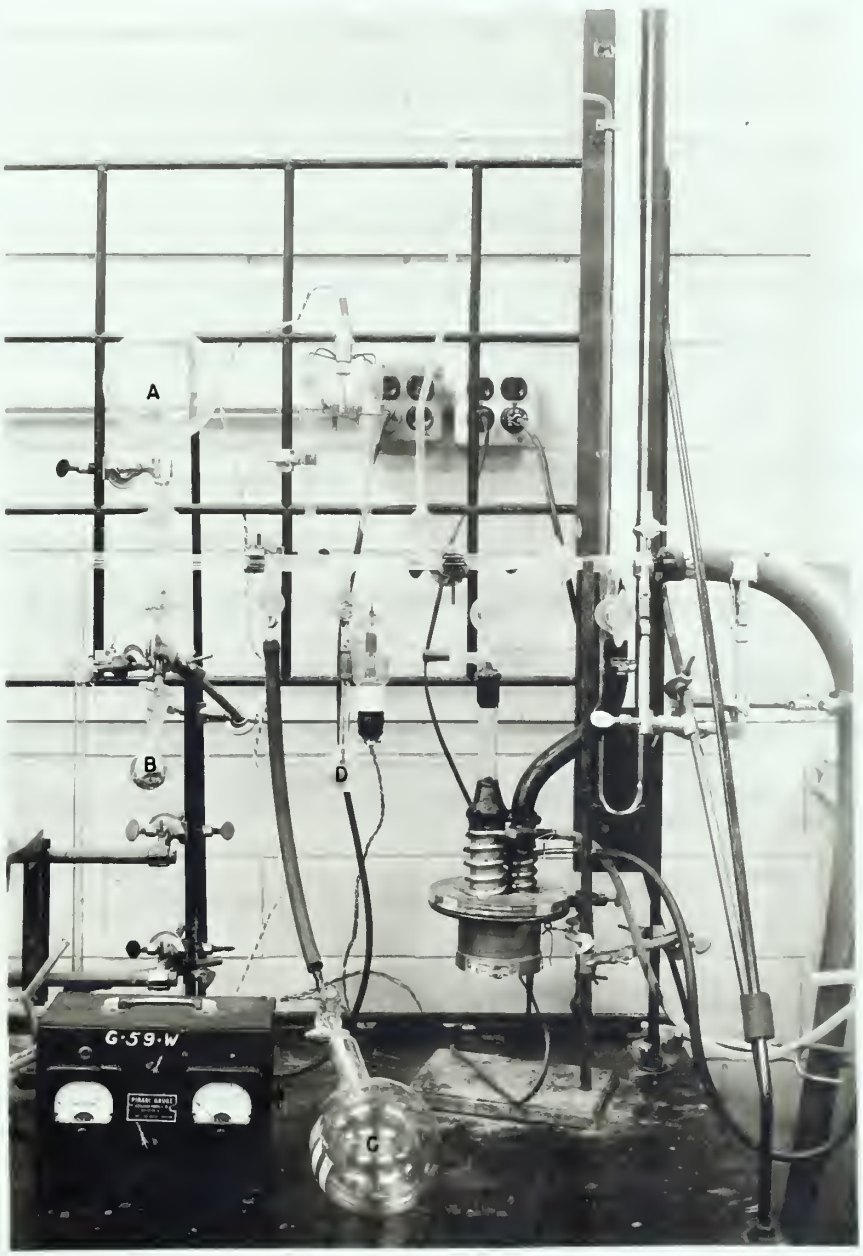
The pressure gauges used were a standard mercury manometer reading from 0-90 cm. Hg. and a pirani gauge. The pirani gauge was manufactured by Distillation Products, Inc. and read pressures from about 1 cm. Hg. down to less than one micron.

C. Preparation of Filling Mixture

A flask fitted with a glass taper and a stopcock was evacuated to below one micron, flushed out with argon to a pressure of 40 cm. Hg. ten times and then filled with 99.8% purity argon. A flask was next fitted with a taper and filled with 100% ethanol. The alcohol was then de-gassed by placing the alcohol under low pressure for 10 hours. These

Fig. 2. Vacuum equipment

A. Mixture flask
B. Geiger-Muller tube
C. Argon flask
D. Alcohol flask


A
B
D
G-59-W
C

two flasks were attached to the manifold. The flask which was to contain the mixture was then evacuated and flushed out several times with alcohol vapor then with argon. The alcohol vapor was then introduced into the mixture flask to the vapor pressure of the alcohol at room temperature (4 to 4.5 cm. Hg.). The stop cock was then closed from the alcohol flask and argon introduced to bring the pressure to ten times the vapor pressure of the alcohol vapor. This gave an alcohol vapor pressure of 10% of the total pressure. This was allowed to set for 24 hours to assure complete homogeneity of the mixture.

The Geiger-Müller tube was evacuated to one micron for 24 hours to permit any gas that might be dissolved in the surfaces of the tube to be expelled. The tube was flushed out five times and filled to a pressure of 10 cm. Hg. from the mixture flask.

D. Test Equipment

The test equipment was used as shown in Figure 3. The source was a Co^{60} source placed 72 inches from the center of the tube and collimated by the use of lead bricks. The tube was placed in the collimated gamma beam and rotated to varying angles in 30° increments in a horizontal plane. As shown in Figure 3 this allowed the anode to be rotated to all

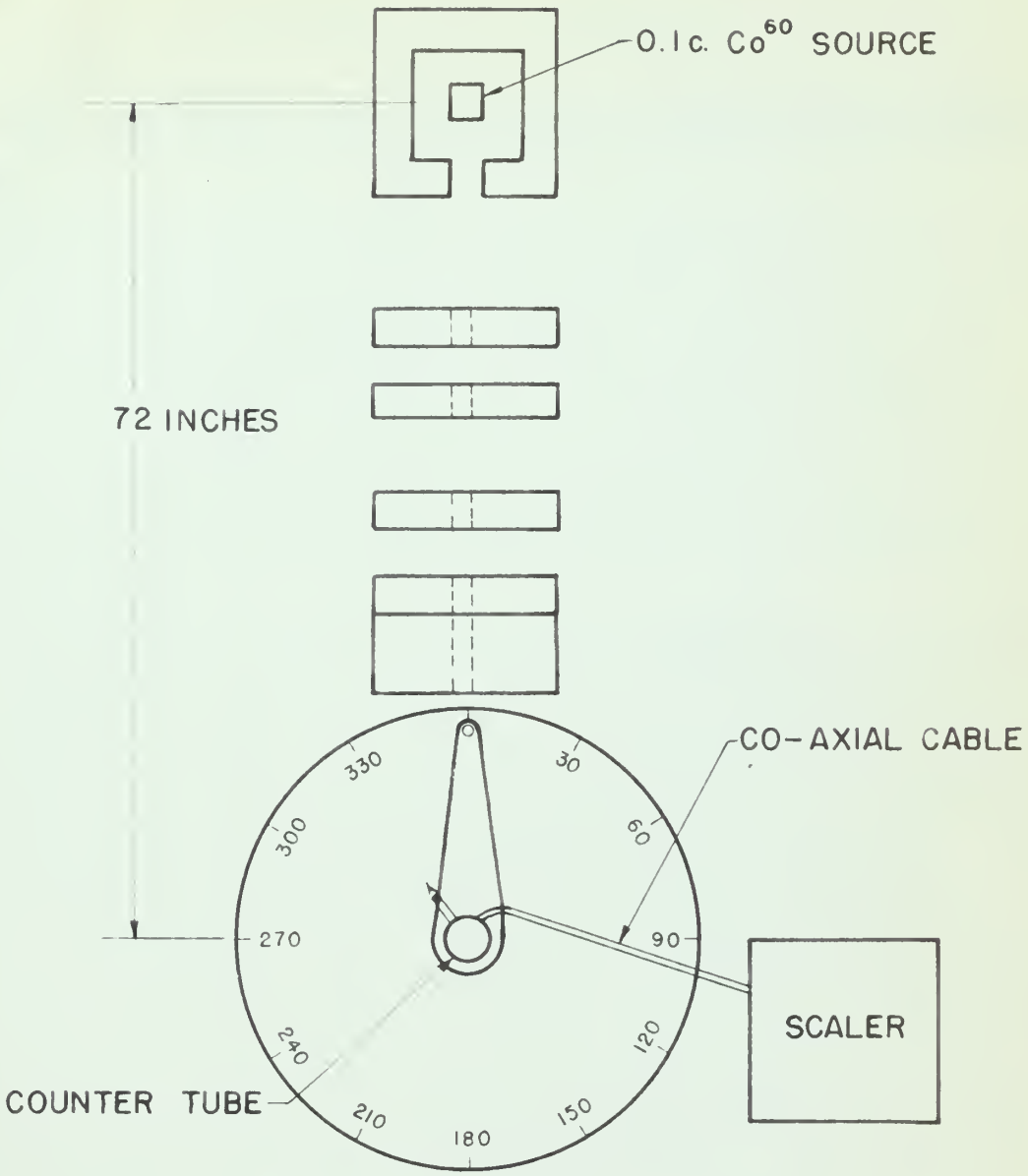


Figure 3. Plan view of the test equipment for determining the directional characteristics of a spherical Geiger-Muller tube

possible orientations in relation to the gamma beam. A plateau curve was obtained and the tube was then operated on the plateau through the remainder of the runs as the tube was rotated. Ten-minute runs were made in taking the experimental data.

V. RESULTS AND CONCLUSIONS

The first tube used was connected to the counter and the voltage increased with a Co^{60} source placed next to the tube to obtain a plateau curve. Upon reaching 650 volts the tube went into continuous discharge without a count before this point. This voltage was very low for continuous discharge considering the type of tube. The reason for the discharge was because of spurious discharges caused by a rough anode and anode lead.

Great care was used in the construction of the second tube to insure proper operation. The tube was filled as before with 10 cm. Hg. pressure. The tube started to count at 1050 volts with a very short plateau extending about 40 volts and had a relative plateau slope between 0.524 and 0.776 per 100 volts. This indicated that there may have been an impurity in the counting gas that may have come either from air leaking into the tube through the stopcock or some impurity introduced in the filling procedure. The plateau curve is shown in Figure 4 and the data in Table 1 of the Appendix.

The counting rate for varying positions of the counter tube is shown in Figure 5 and in Table 2 of the Appendix. The counting rate for varying positions did not vary more

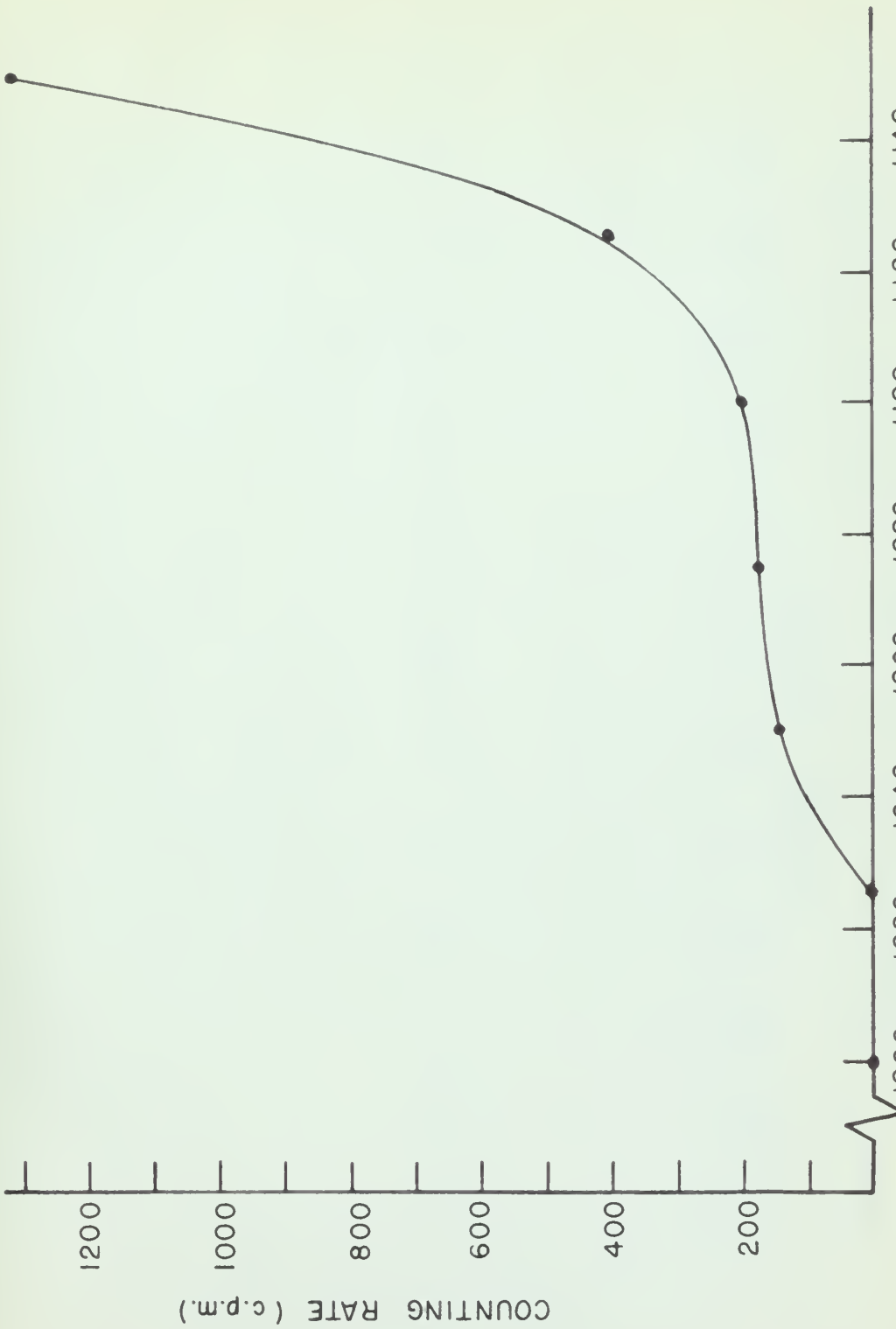


Figure 4. Plateau curve for spherical Geiger-Müller counter

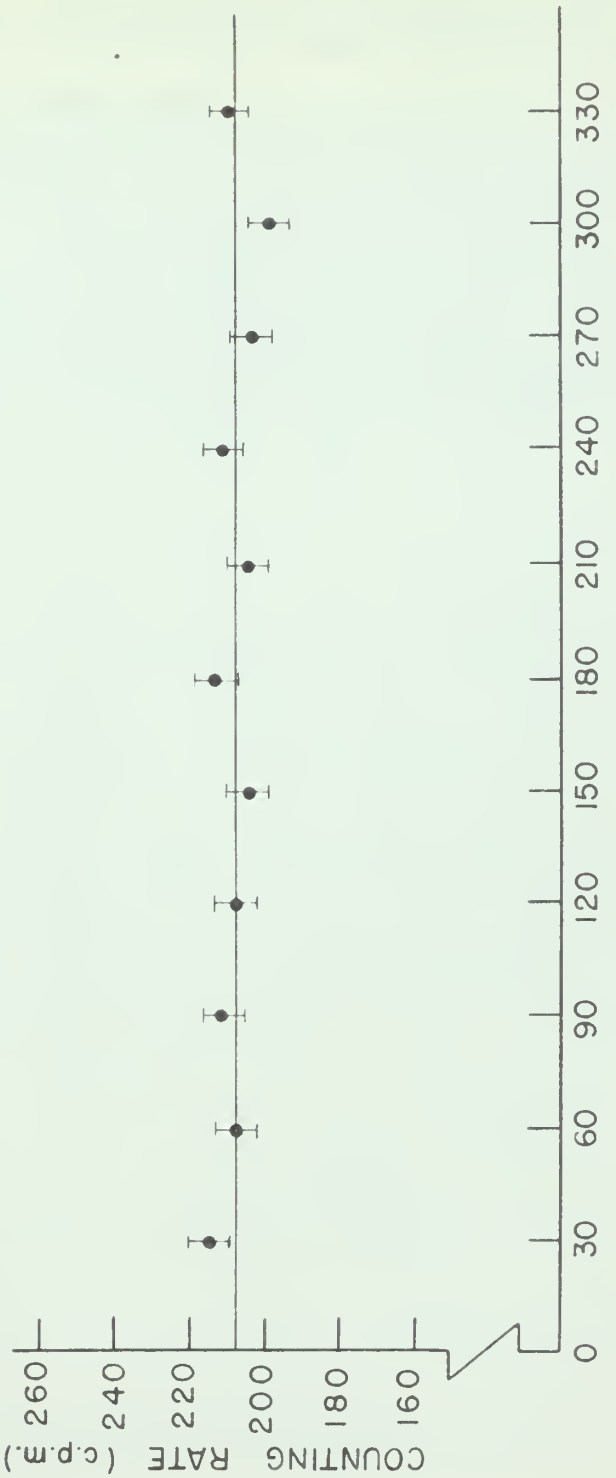


Figure 5. Directional characteristics of a spherical Geiger-Müller counter; vertical lines show the standard deviation of the individual measurements

than one standard deviation except at one position of the counting tube. This might be expected from the statistical nature of the measurements. Hence the tube is non-directional as predicted.

The tube should have use as a dose measuring device or to measure the absolute activity of solutions.

The slope of the plateau and the short plateau could be corrected by changing the pressures and composition of the filling gas.

VI. SUGGESTIONS FOR FURTHER STUDY

It is suggested that this design of tube be further investigated to determine its characteristics. Characteristics such as dead time and geometry factors should be determined. Changes in filling pressures, mixtures and percentage of the organic phase should be investigated. In this manner an optimum mixture for this particular design could be developed.

There is a place for such an instrument particularly in dosimetry. It is further suggested that an effort be made to reduce the thickness and increase the uniformity of the tube wall so that both beta and gamma rays may be more efficiently counted. The researcher must, however, be prepared for a number of disappointments before a tube satisfactorily operates and he should not attempt the problem if his time is limited.

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IX. APPENDIX

Table 1. Data for determination of plateau curve

Voltage	Counts	Time (min.)	Counting rate (c.p.m.)
1050	1443	10	144.3
1075	1768	10	176.8
1100	2001	10	200.1
1125	4022	10	402.2
1150	13156	10	1315.6
1175	37795	10	3779.5
1200	87226	10	8722.6

Table 2. Data for determination of directional characteristics using a voltage of 1090 volts

Position (degrees)	Net counts	Time (min.)	Counting rate (c.p.m.)	Std. dev. (c.p.m.)
0	2083	10	208.3	±4.6
30	2151	10	215.1	±4.6
60	2007	10	200.7	±4.5
90	2104	10	210.4	±4.6
120	2082	10	208.2	±4.6
150	2038	10	203.8	±4.5
180	2123	10	212.3	±4.6
210	2034	10	203.4	±4.5
240	2095	10	209.5	±4.6
270	2019	10	201.9	±4.5
300	1980	10	198.0	±4.5
330	2084	10	208.4	±4.6
Background	400	20	20.0	±1.0